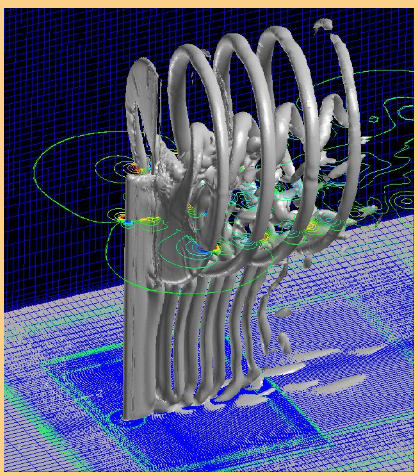
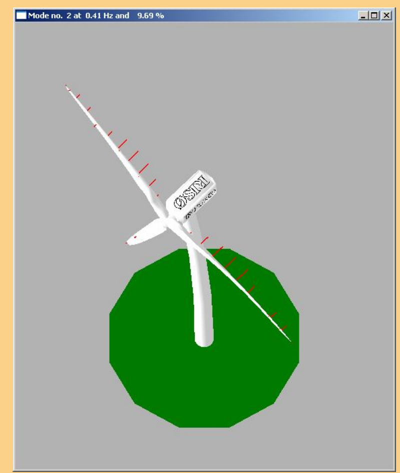
# UpWind



## Aerodynamics and Aeroelastics, WP 2




Flemming Rasmussen

Aeroelastic Design

Wind Energy Department

Risø DTU

# WP2 Aero-dynamics and Aero-elastics OBJECTIVES

Overall: To develop an aeroelastic design basis for large multi MW turbines.

Specific:

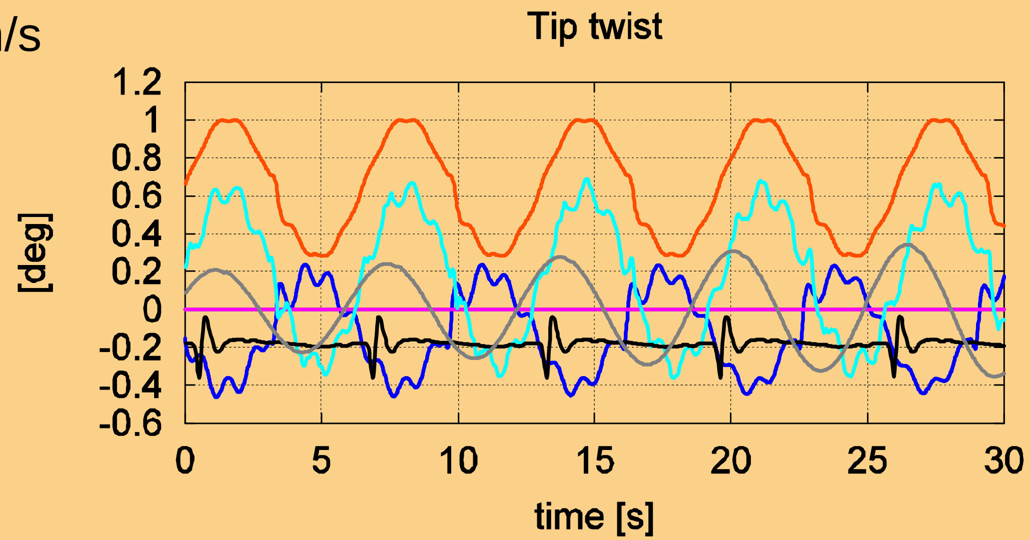
1. Development of **nonlinear structural dynamic** models (modeling on the micromechanical scale is input from WP3).
2. **Advanced aerodynamic models** covering full 3D CFD rotor models, free wake models and improved BEM type models. (The wake description is a prerequisite for the wake modeling in WP8).
3. Models for **aerodynamic control features and devices**. (This represents the theoretical background for the smart rotor blades development in WP 1.B.3)
4. Models for analysis of **aeroelastic stability** and total **damping** including **hydroelastic interaction**
5. Development of models for computation of **aerodynamic noise.**

# WP 2.1 Structural dynamics, large deflections & non-linear effects

Approach

- Identification of important non-linearities in large wind turbines
- Implementation of non-linear beam models in aero-elastic tools

Example: Tip twist deformation,
IEA comparison, RWT, 8 m/s

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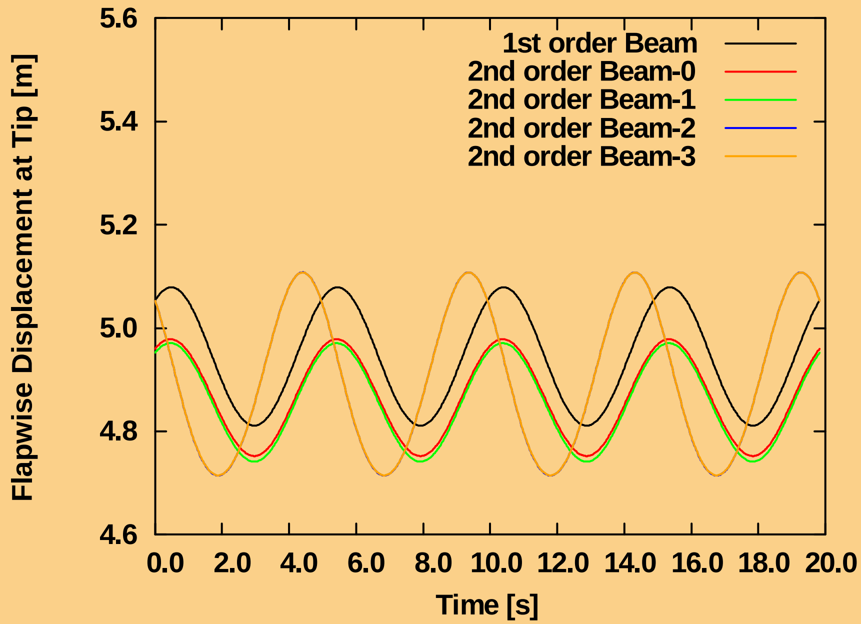
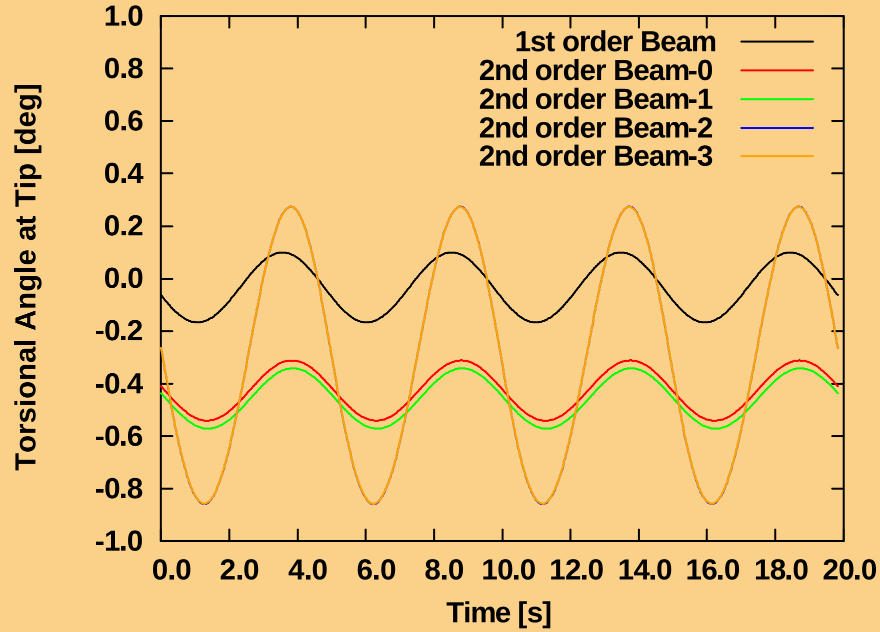
# WP 2.1 Non-linear effects

Additions to the baseline, 1st-order, model

- Formulation of dynamic equations in the deformed state (same structural couplings as in baseline but 2nd-order kinematics and dynamics)
  (2nd order beam-0)
- Tension –torsion coupling terms (2nd order beam-1)
- Bending –torsion coupling terms(2nd order beam-2)
- Pre-twist –torsion coupling term (2nd order beam-3)



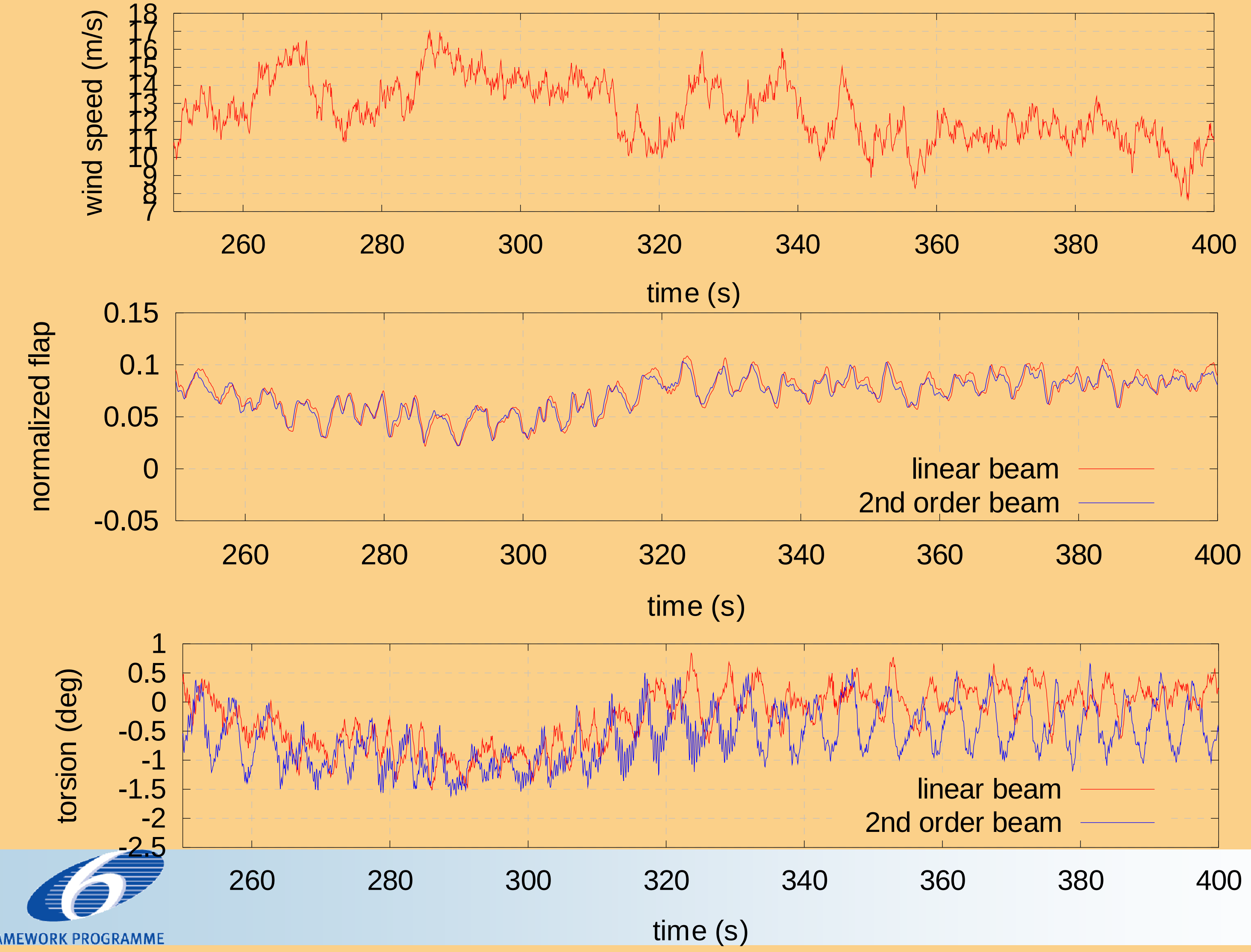






Wind speed: 11m/s

# WP 2.1 Non-linear effects

Linear vs. non linear beam model analysis, NTM at 11.4 m/s



# WP 2.1 Structural dynamics, large deflections & non-linear effects

Summary

- Significant contributions obtained by
  - Formulating the dynamic equations in the deformed state
  - Including bending –torsion coupling terms

# WP2.2 Advanced aerodynamic models

Objectives

- to identify the limitations in the engineering aerodynamic modeling in BEM type codes

Approach

- inter comparison of results of models of different complexity applied on MW rotors, RWT- 5MW
- Shear and turbulence wind inflow for CFD-models

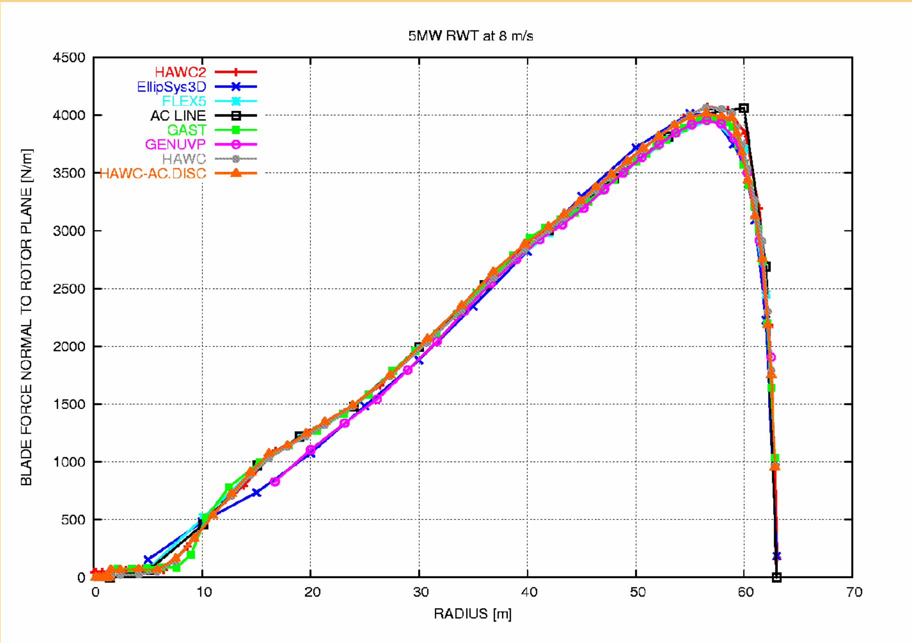
Simulation cases

- uniform inflow on RWT turbine (stiff model)
- strong wind shear in inflow
- unsteady inflow (turbulent)- not yet performed

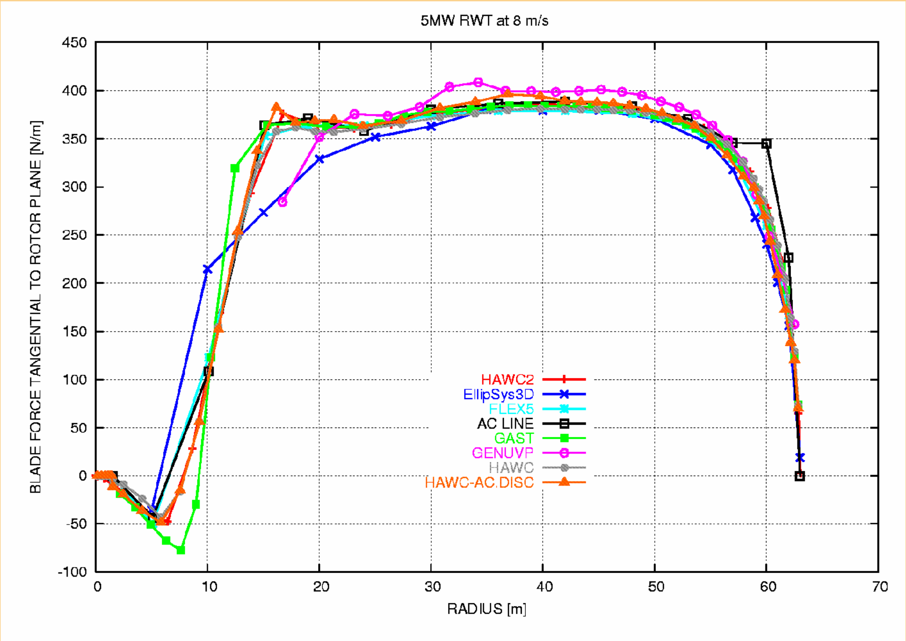
# WP2.2 Blade forces normal and tangential

Simulations with various
codes at 8 m/s

uniform inflow

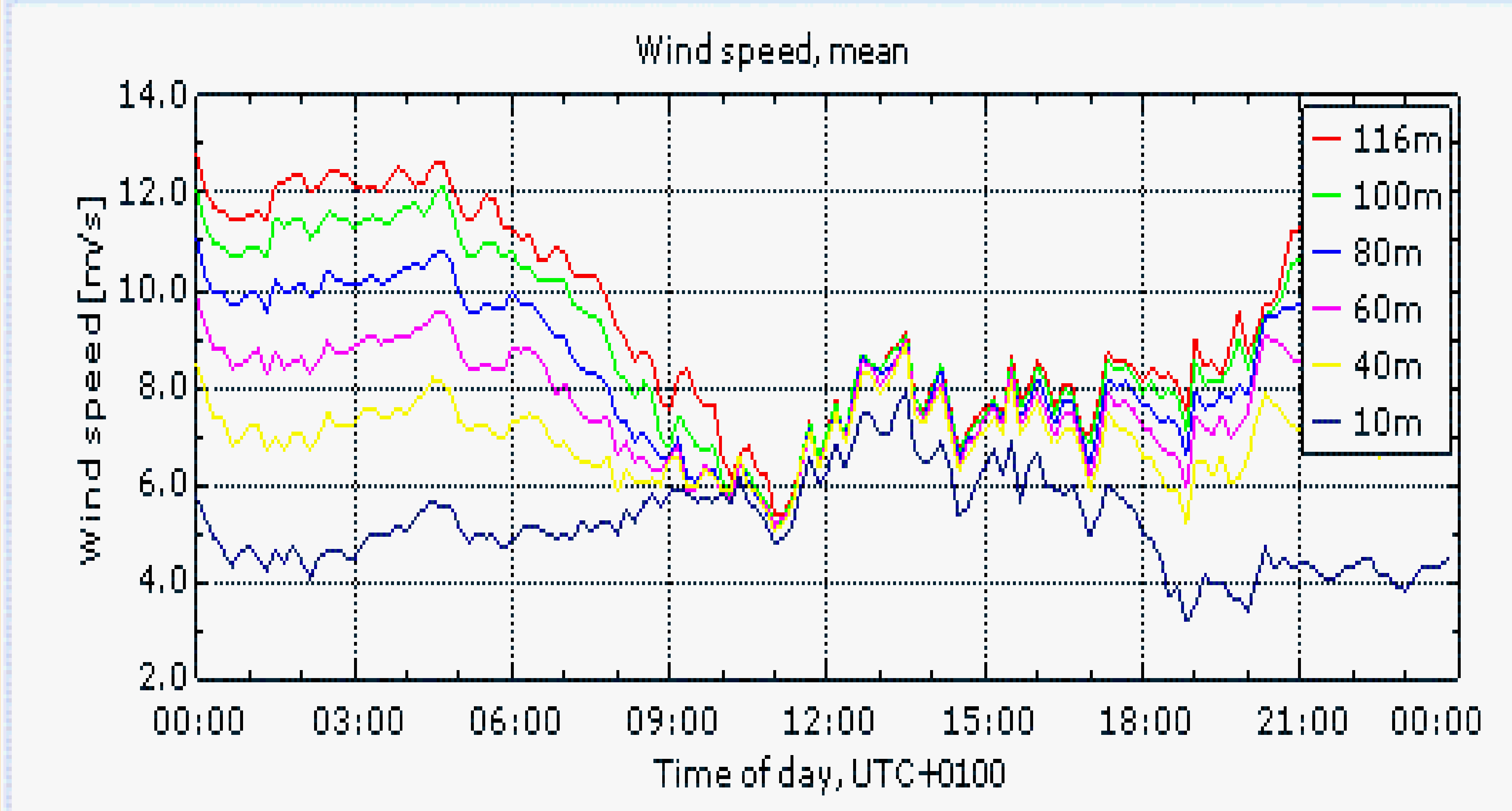



normal




tangential

# Wind speed with height, night- day, Høvsøre

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from http://veaonline.risoe.dk

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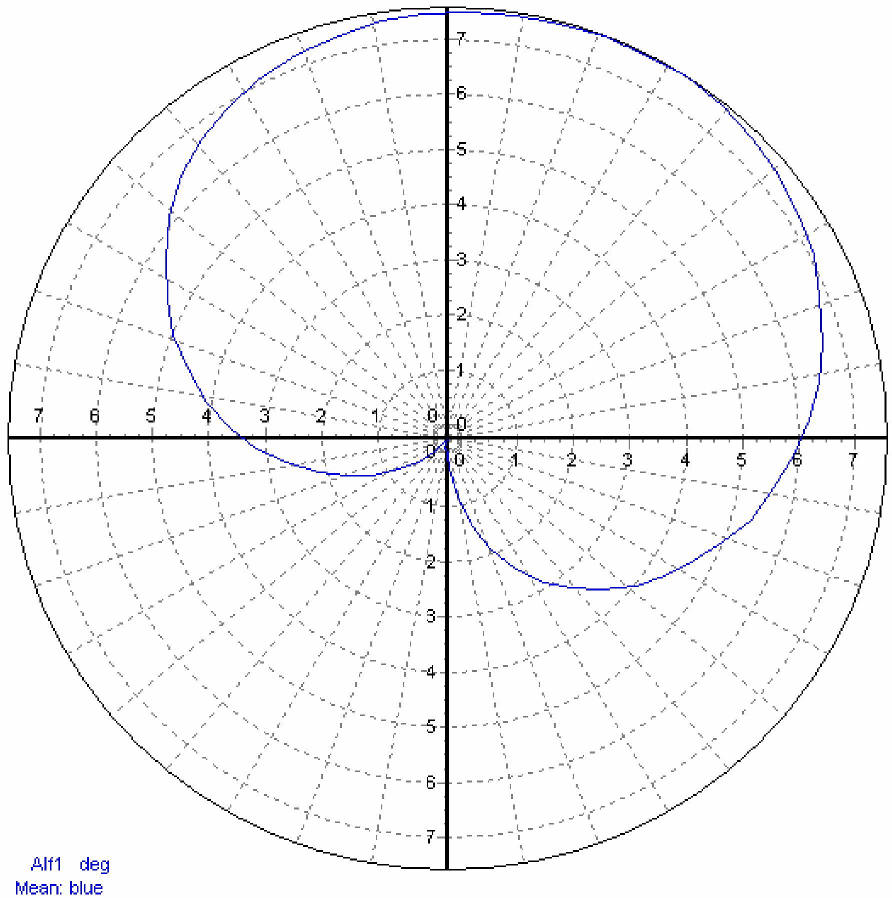
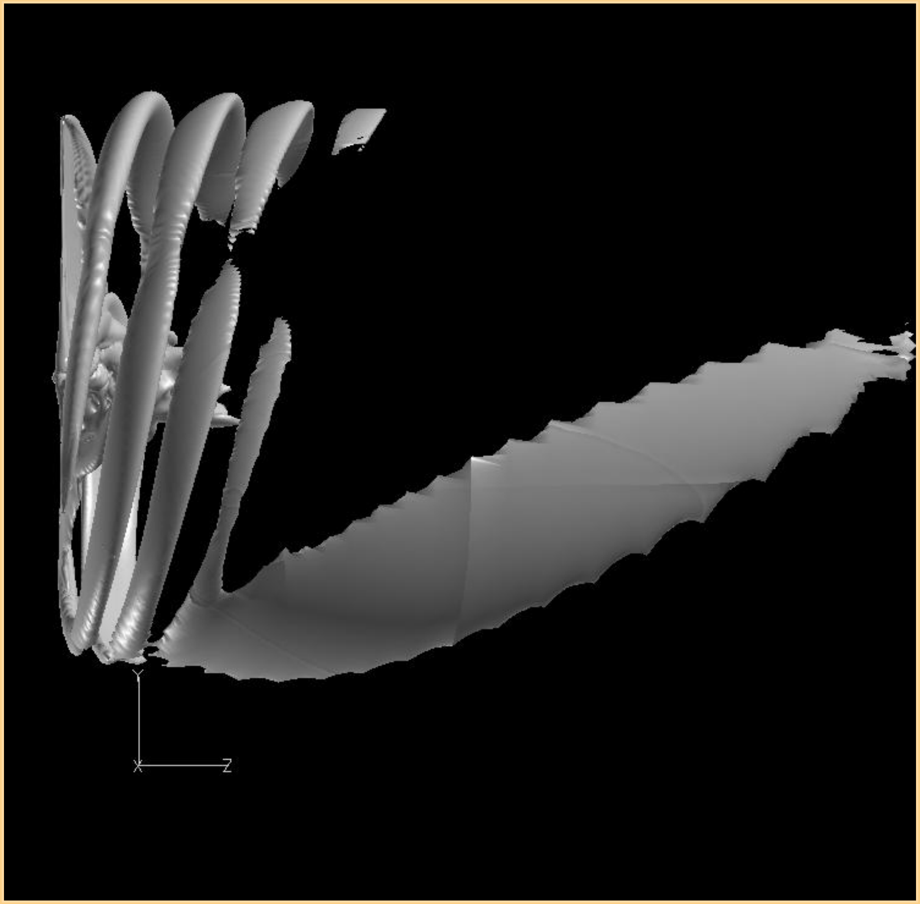
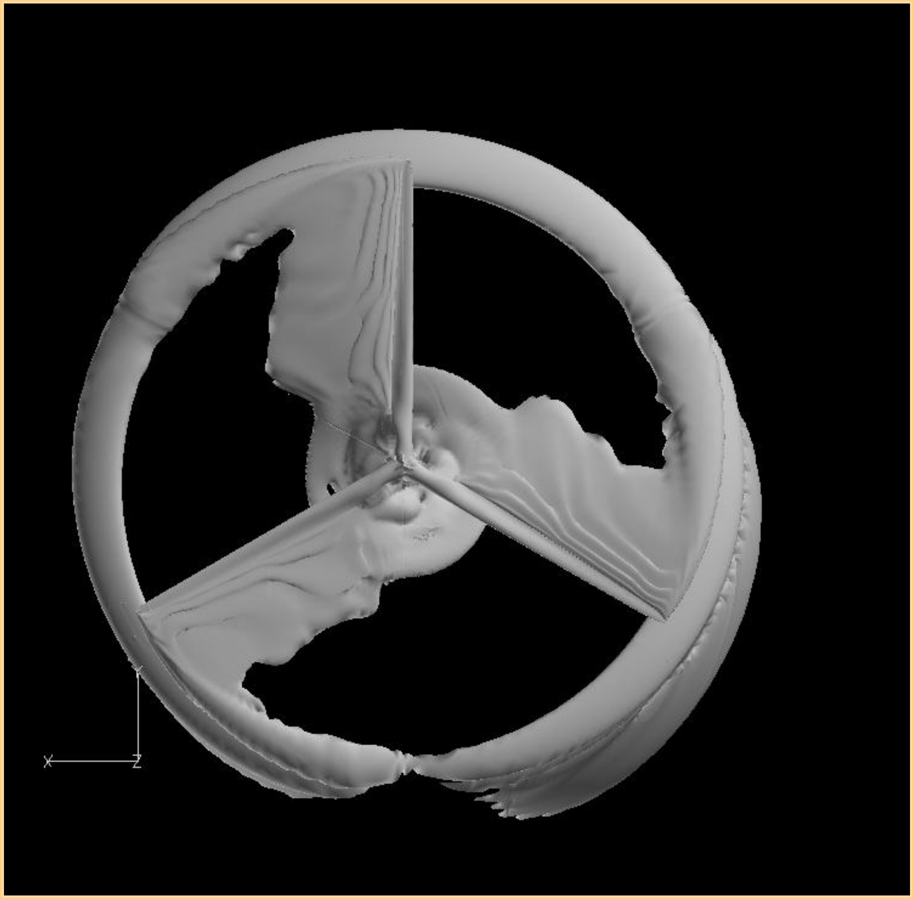
# Measured inflow angle on the NM80 at Tjæreborg during a period with strong shear and low turbulence




Inflow angle

# Wake pattern, CFD with strong inflow shear

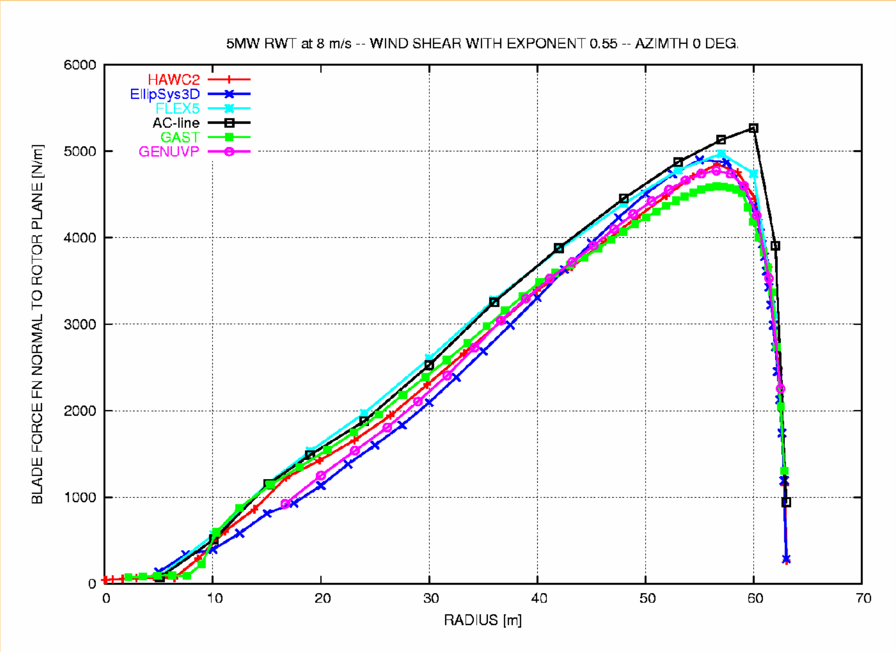




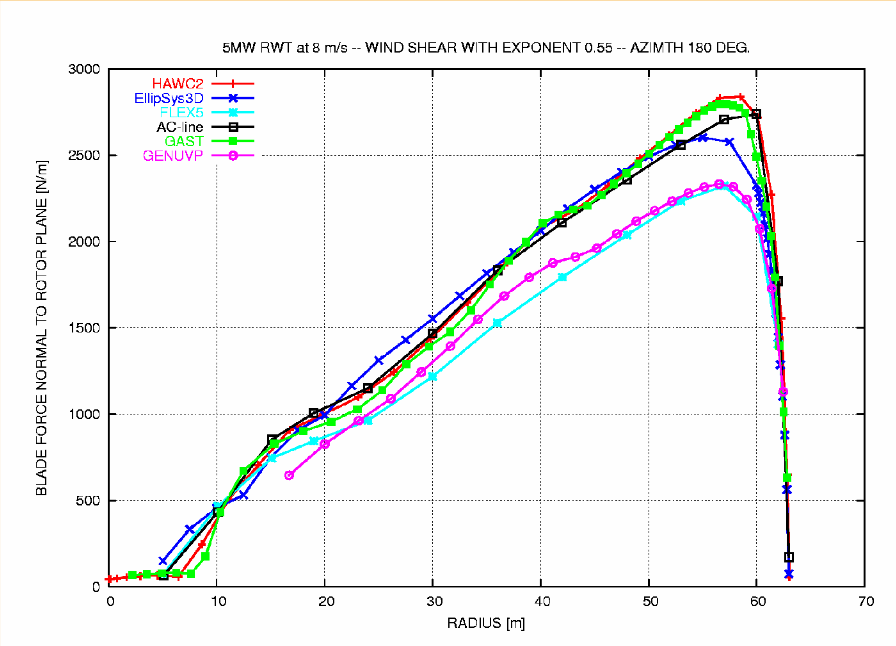
# WP2.2 Blade normal force

8 m/s - strong inflow shear - exponent 0.55, $U(z) = U_{hub}\left(\frac{z}{z_{hub}}\right)^{0.55}$

blade up




blade down

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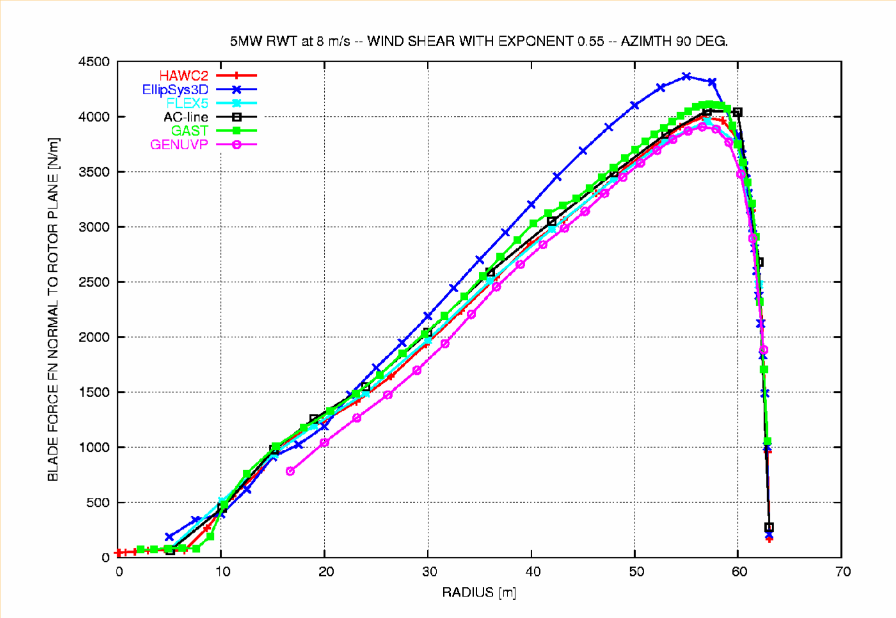
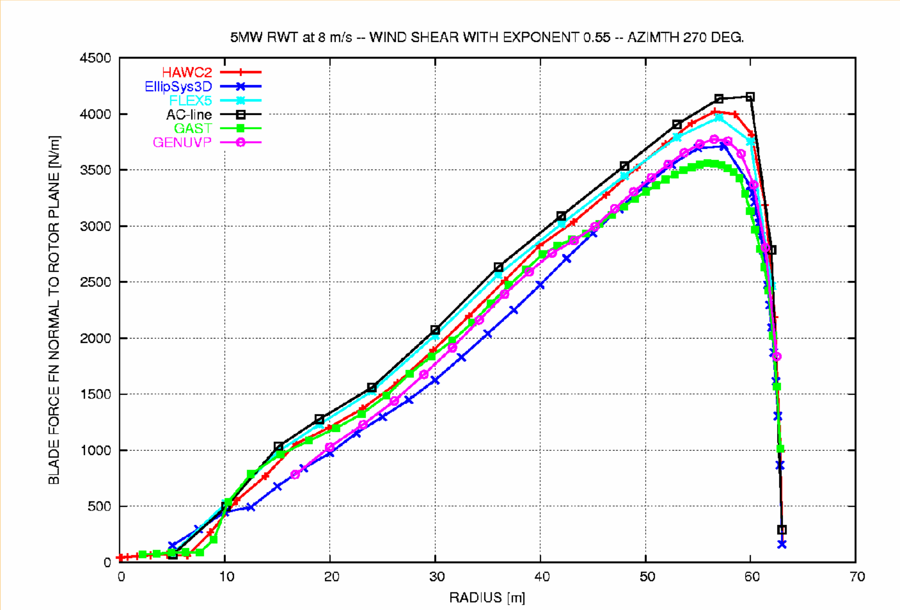
# WP2.2 Blade normal force

8 m/s -- strong inflow shear - exponent 0.55

blade 90 deg.

blade 270 deg.

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# WP2.2 Advanced aerodynamic models

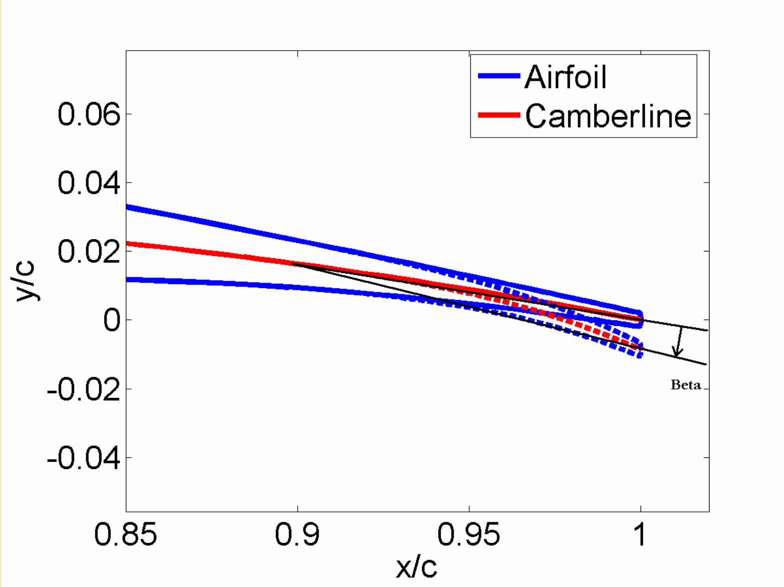
Summary

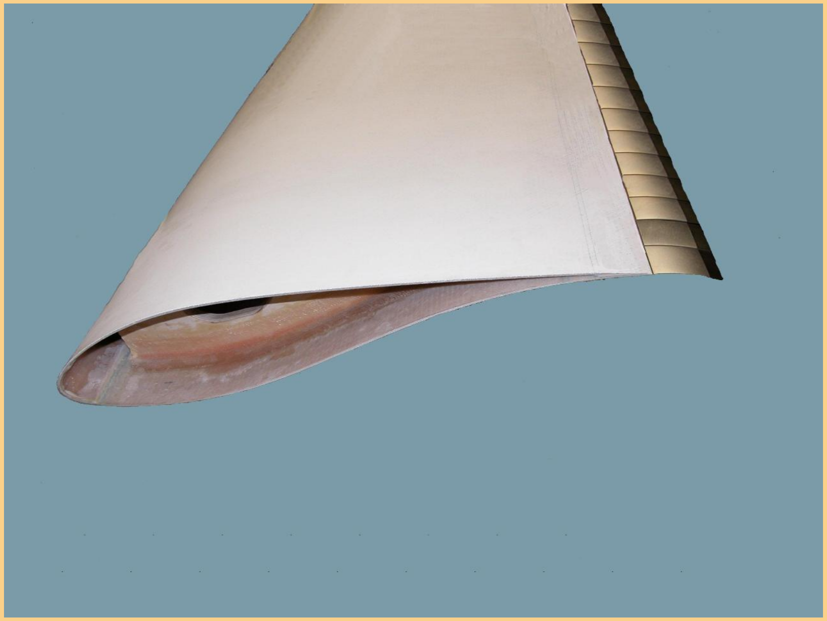
- uniform inflow and low wind speed a good correlation is found between all models
- at high wind speed and uniform inflow considerable deviations are seen on the load distribution along the blade
- for the strong wind shear case, considerable deviations between the models are seen

# WP 2.3 Advanced control features and aerodynamic devices

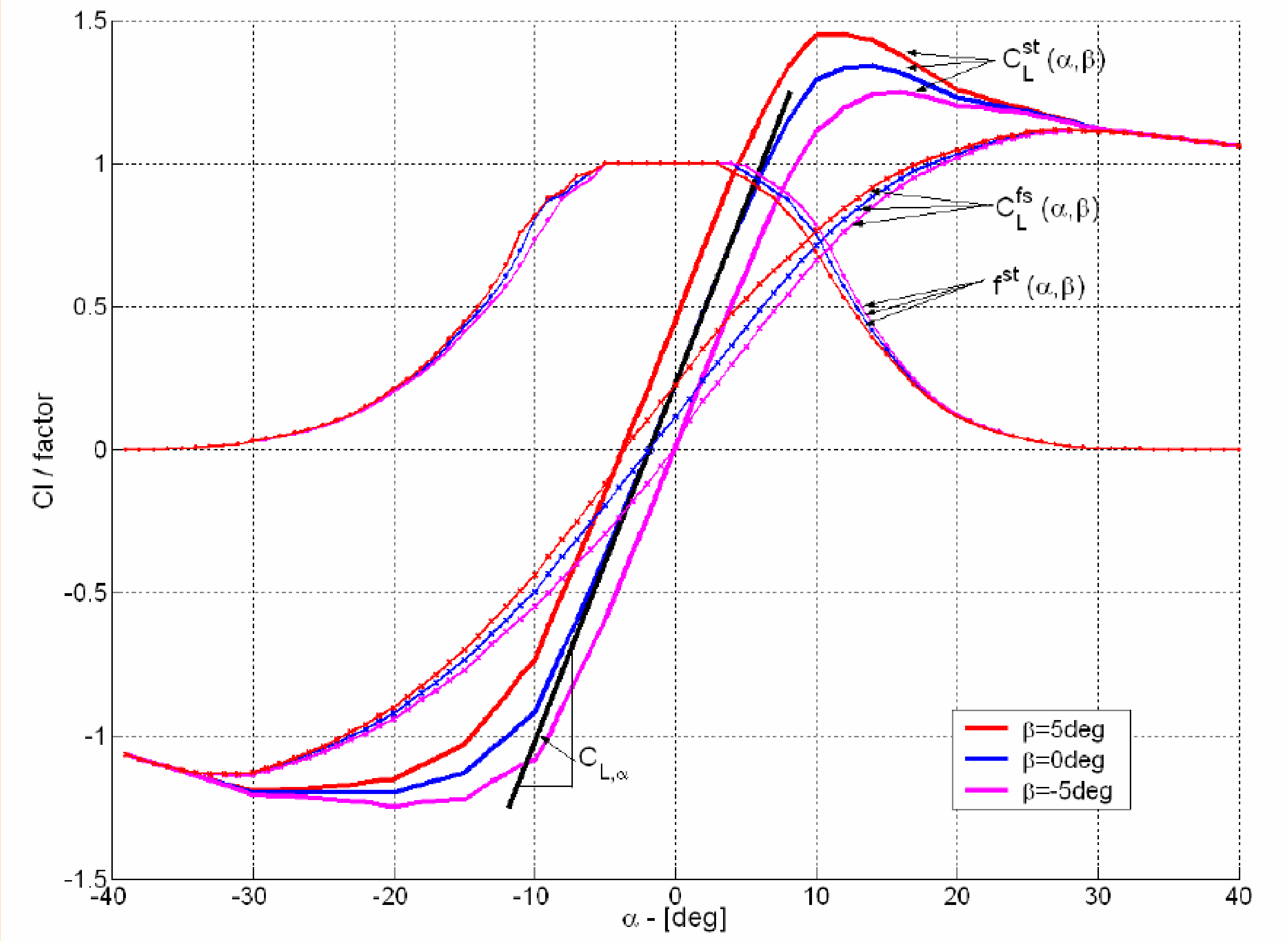
Approach:

- Develope detailed models for structural and aerodynamic analysis for a few promising flow control concepts (in close corporation with WP 1A5).
- Deformable camberline.



# Dynamic Stall model: Main input: $C_L^{st}(\alpha,\beta)$

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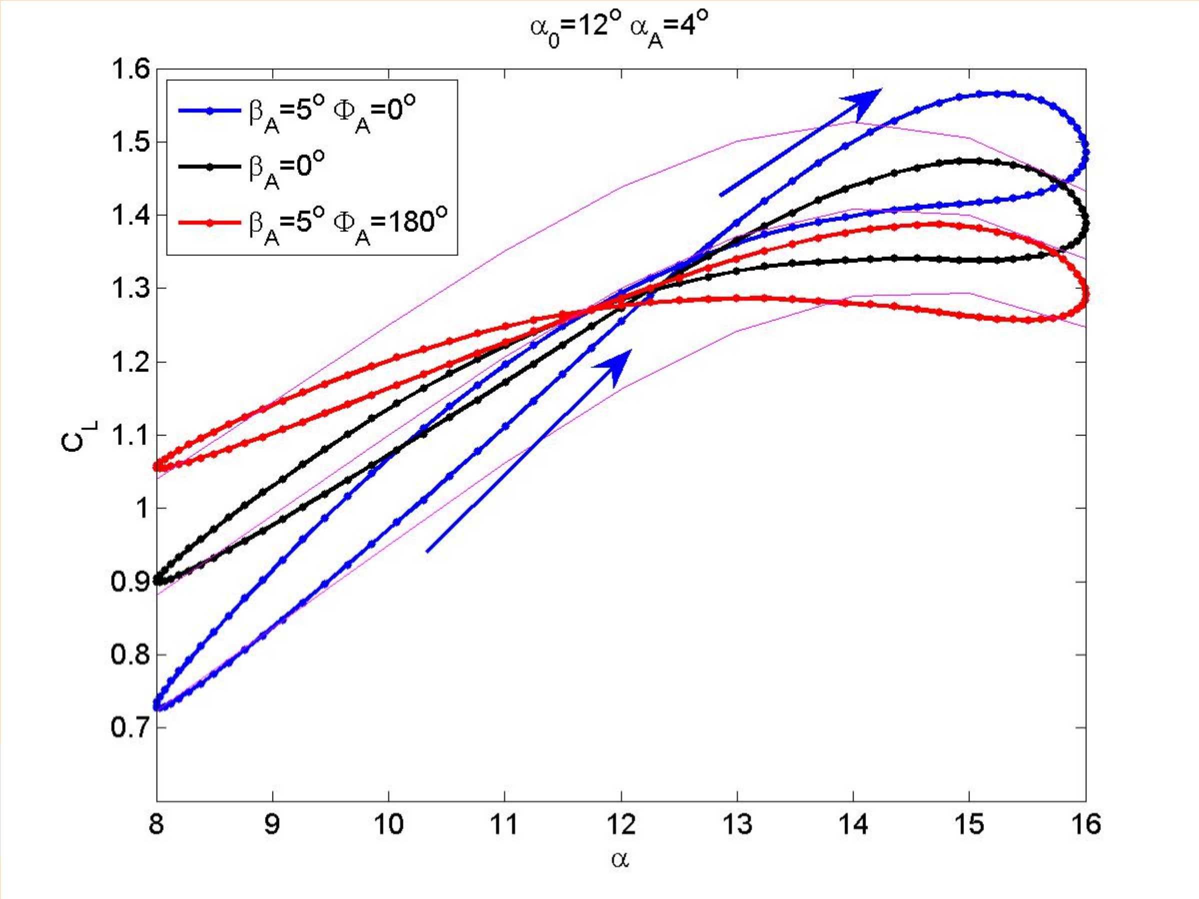
# Dynamic Stall: Harmonic Alpha and Beta

Blue: Alpha and Beta in phase

Black: No Beta

Red: In counter-phase (180° shift)

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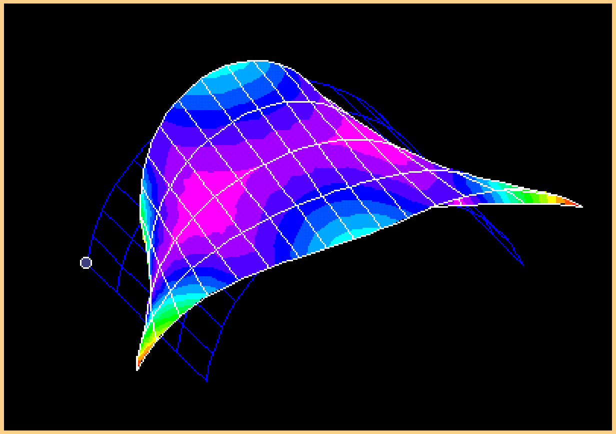
# WP 2.4: Aeroelastic stability and total damping including hydrodynamics

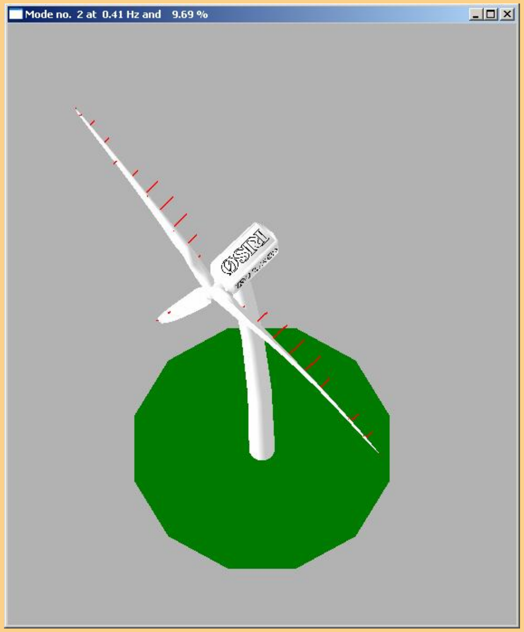
Approach:

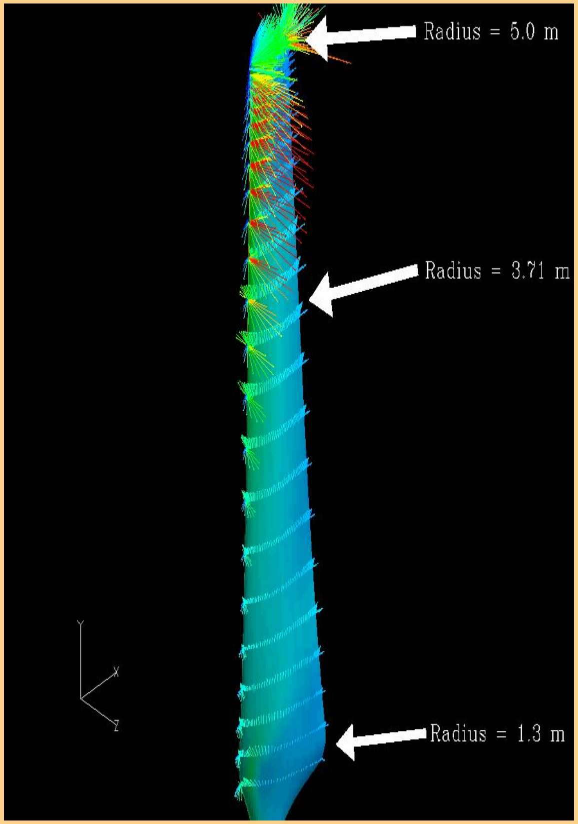
•Aerodynamic damping and aeroelastic stability of the RWT 5 MW turbine

•Blade structural damping model

•CFD-structure coupling

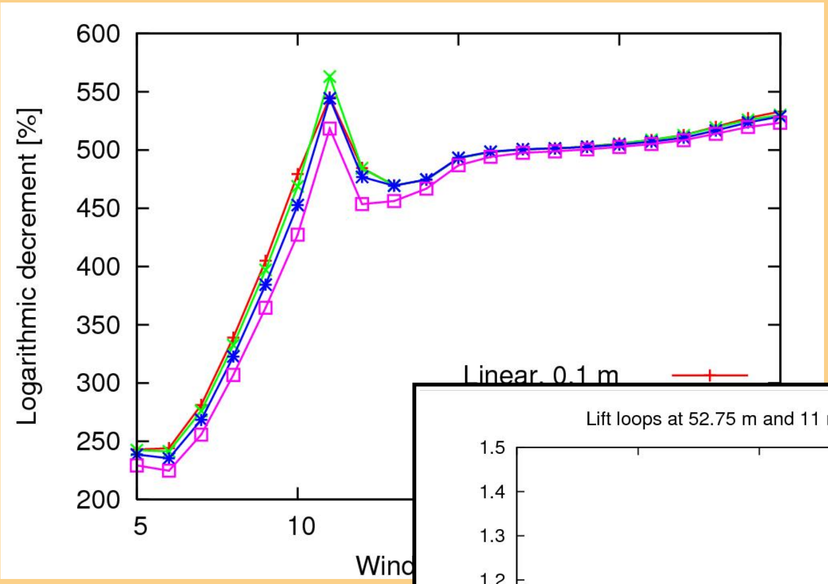




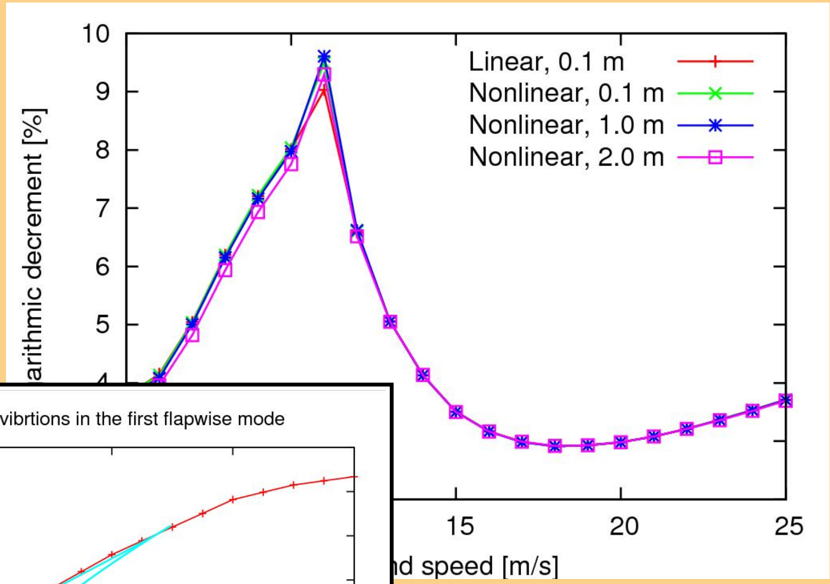



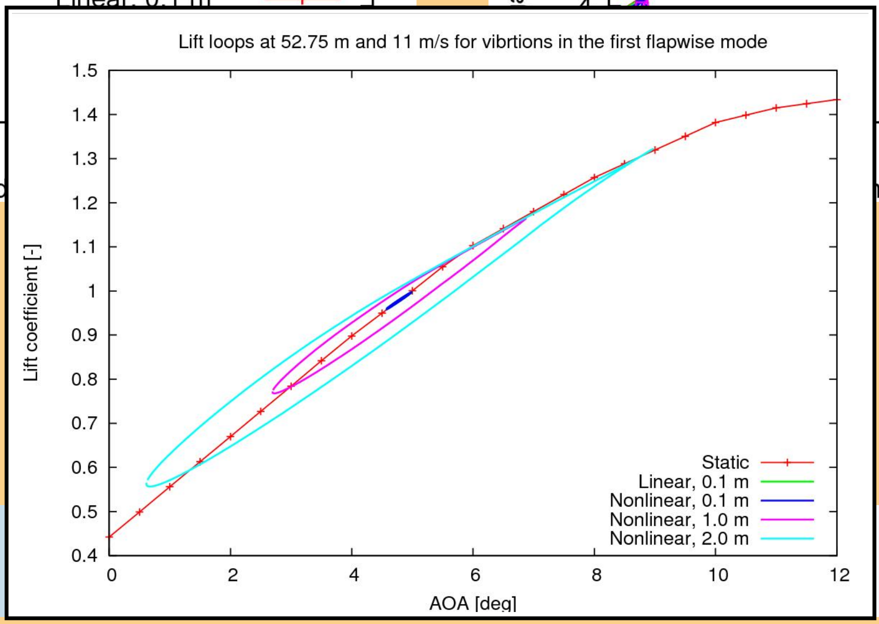
# WP 2.4: Aerodynamic damping of blade modes for RWT 5 MW

First flapwise mode




First edgewise mode

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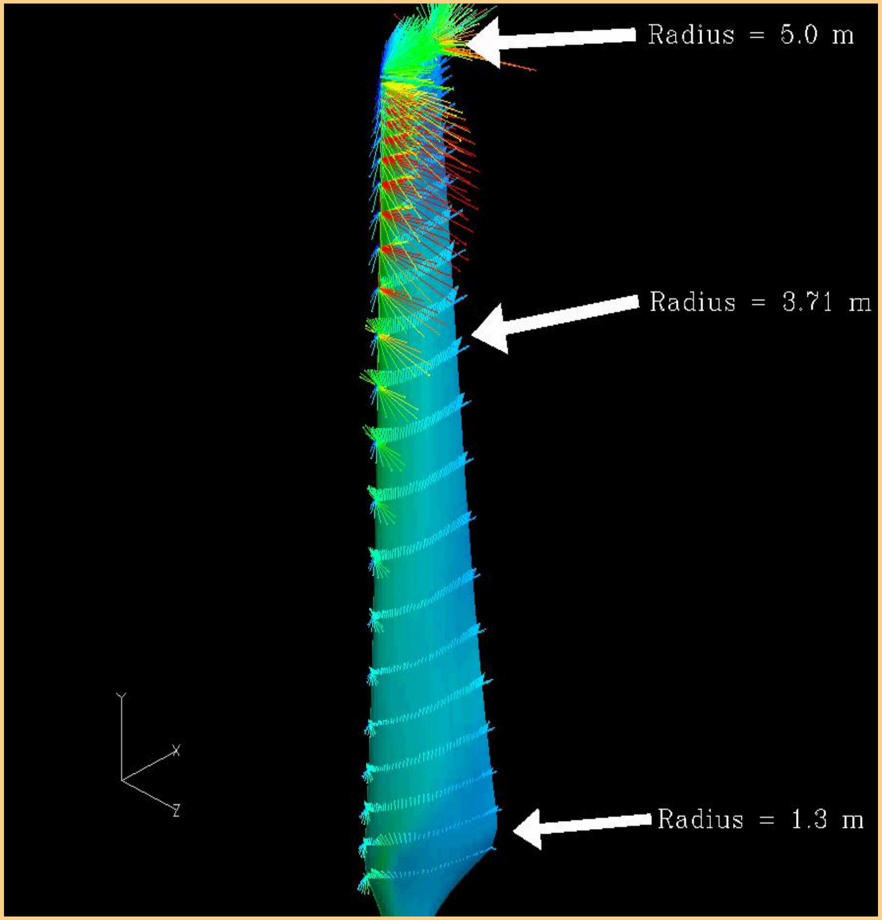
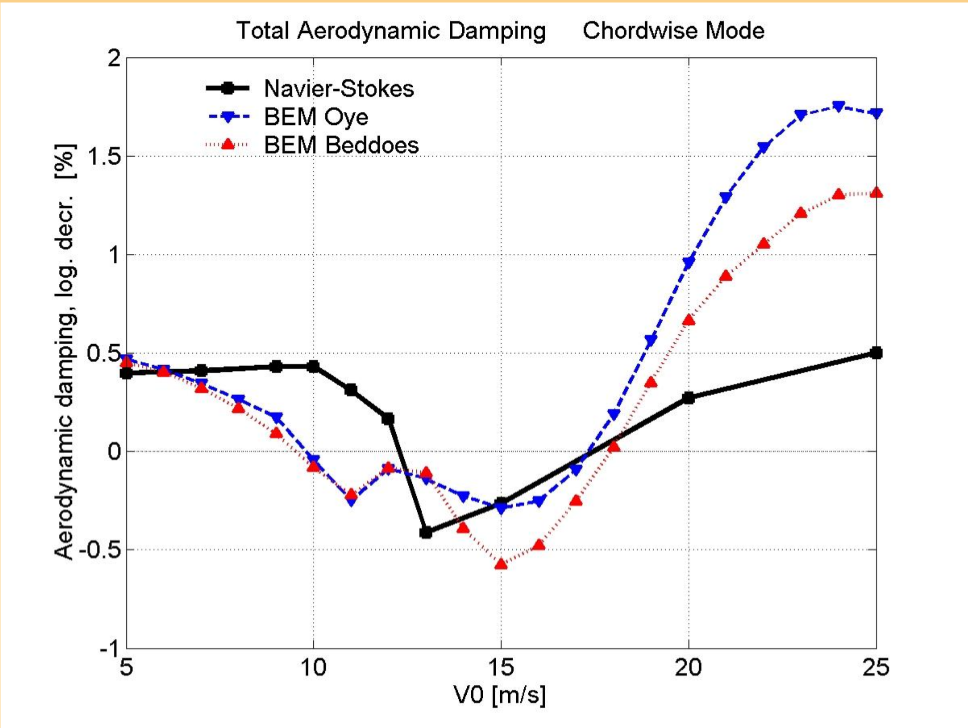
# WP 2.4: Aeroelastic stability and total damping including hydrodynamics.

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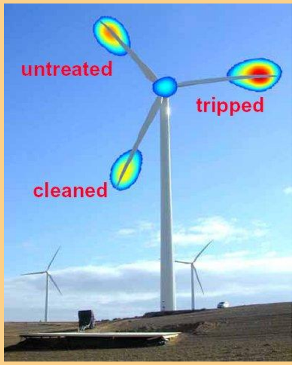
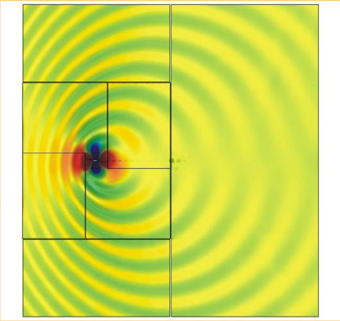
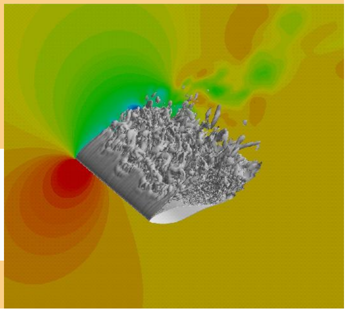
# WP 2.5 Computation of aerodynamic noise – coupled CFD-CAA models

Approach:

- Boundary-layer experiments to validate and select appropriate turbulence models.
- Improve the capability of existing stochastic turbulence models for CFD-CAA coupling.
- Development of CAA schemes for computation of aeroacoustic noise generation as function of detailed turbulence data from CFD computation on a 2D airfoil.





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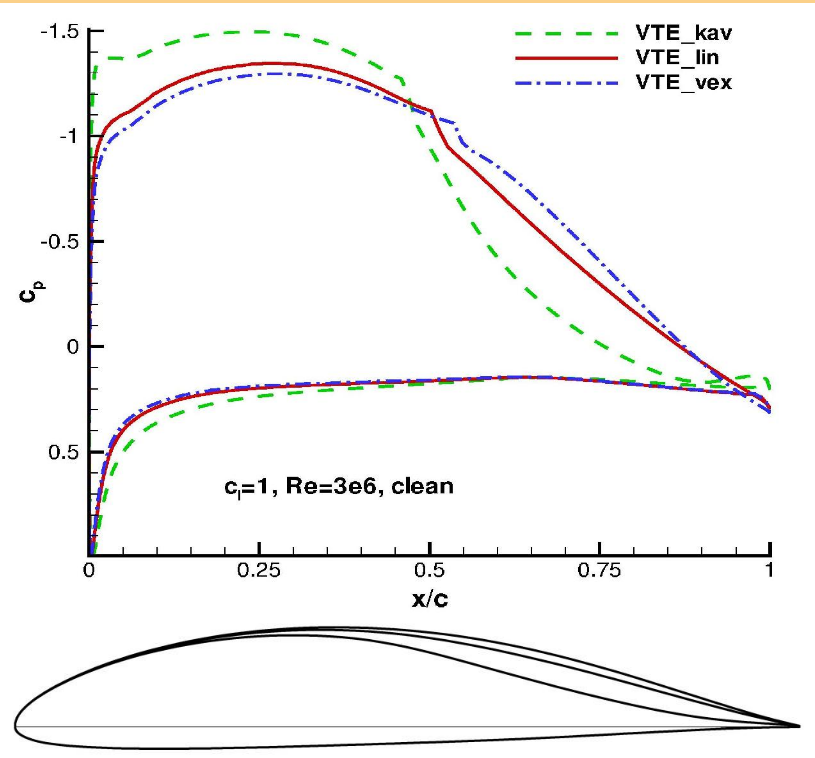
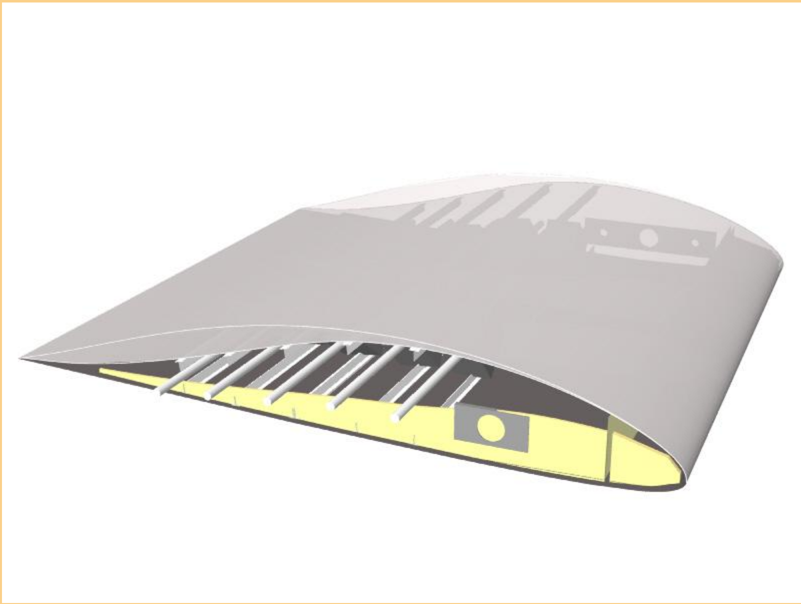
# Test Cases : VTE Model Developed at LWT (SIROCCO Project)

- goal: variation of boundary-layer parameters at trailing-edge
- requires strong contour change over major part of chord length
- three variations: VTE_lin, VTE_kav (and VTE_vex)



Wind tunnel model
with adjustable shape

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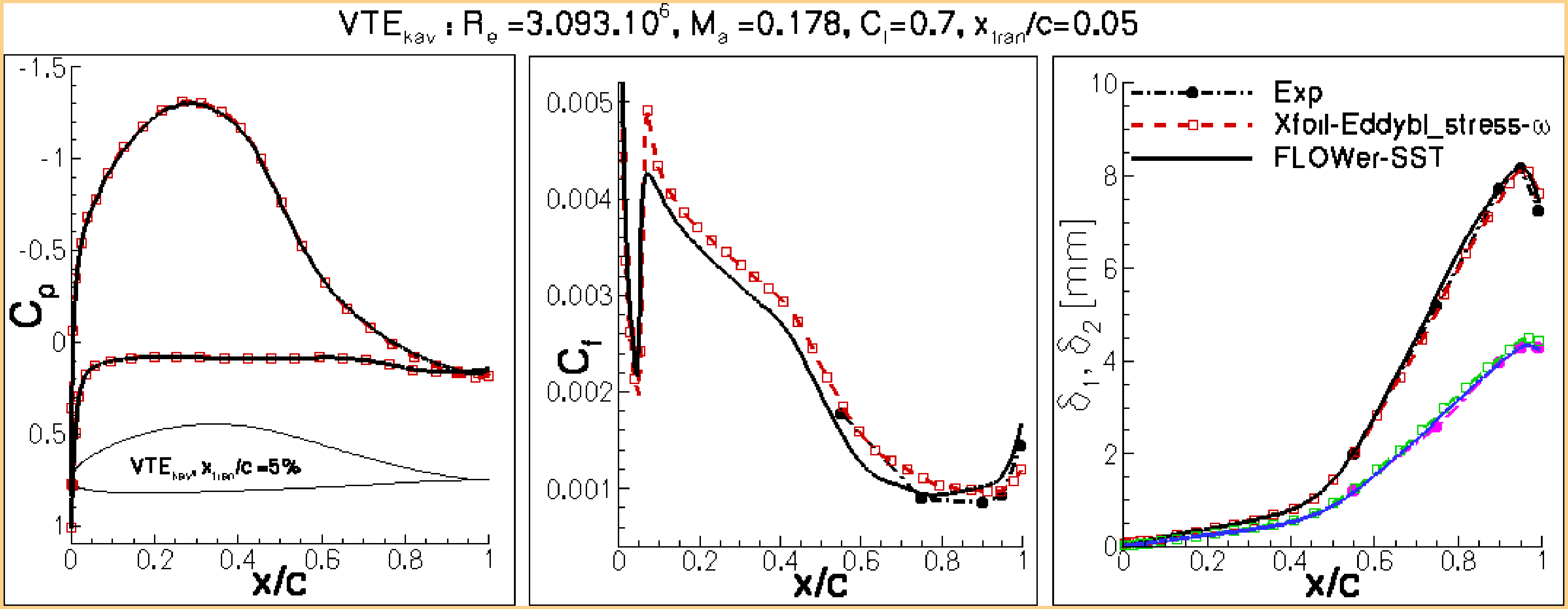
# Results: VTE_kav, Cl=0.7, BL Parameters

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# Results: VTE_kav, Cl=0.7, Noise Spectra